Transactions of the Royal Society of S. Aust. (2002), **126**(1), 39-44.

A LATE PLEISTOCENE OCCURRENCE OF *DIPROTODON* AT HALLETT COVE, SOUTH AUSTRALIA

by N. S. PLEDGE[1], J. R. PRESCOTT[2] & J. T. HUTTON[3]

Summary

PLEDGE, N. S., PRESCOTT, J. R. & HUTTON, J. T. (2002) A late Pleistocene occurrence of *Diprotodon* at Hallett Cove, South Australia. *Trans R. Soc. S. Aust.* **126**(1), 39-44, 31 May, 2002.
Despite *Diprotodon* fossils occurring widely across Australia, until recently, few finds have been adequately dated. This is due to several reasons, primarily the inadequacies of the radiocarbon methods. New dating methods, which coincidentally increase the datable age range, have been developed in recent years. One of these is thermoluminescence (TL) dating. Yet there are still few reliably dated *Diprotodon* specimens because they must be found and dated *in situ*. A chance discovery in 1992 gave the authors an opportunity to test one of these new methods and at the same time solve a thirty year old mystery. An articulated portion of a *Diprotodon* skeleton found at Hallett Cove is associated with sediment TL-dated to about 55 000 years, and is also a possible source for a fossil tooth found on the nearby beach in 1971.

KEY WORDS: *Diprotodon*, Hallett Cove, thermoluminescence dating, late Pleistocene.

Introduction

Many specimens of *Diprotodon* have been found since its discovery by Major Mitchell in the Wellington Valley, NSW, in the early 19th Century, and precise ages for this, the largest known marsupial, have long been sought. Many, if not most, discoveries were made before the development of the C-14 method of radiometric dating. Others were demonstrably beyond the datable age range and radiocarbon dating of older material has been shown to be unreliable (Chappell *et al.* 1996; Roberts *et al.* 2001). Still others could not be dated for want of sufficient preserved carbon.

In 1992, Mr T. Westlake, whilst walking his dog in a newly designated council reserve at Hallett Cove (Fig. 1), 25 km south-southwest of the city of Adelaide, noticed what appeared to be a large white bone (Fig. 2) eroding out of an old exposure on a former private road. Closer examination supported this identification, and Mr Westlake subsequently informed the South Australian Museum, although he was sure that the relevant people would have known about it already. The occurrence was not known and a visit was immediately organised.

On 26 June, 1992, Mr Westlake guided the senior author and student Gavin Prideaux to the site, an old road-cutting through a spur of hillside overlooking the Field River, not far from the beach at Hallett Cove (about 35° 4′ 9″ South, 138° 29′ 8″ East). The bank was more than 2 m high, and the bone was exposed about 1.5 m below the top and about 2 m above the surface of the nearby bridge. Across the road, the hillside fell steeply to the river about 5 m below. The bone was examined *in situ* and appeared to be part of the pelvis of a large animal and, because it was fossilised and so large, probably of a diprotodontid. With some difficulty, the bone was excavated without greatly enlarging the cutting and plaster-jacketted for transport.

Materials and Methods

The jacket containing the specimen was opened in the laboratory and the sediment removed from around the bone by scraping with a small dental tool, often when the soil had been softened with water. The bone was hardened piecemeal during this process, using a dilute solution of Bedacryl® in acetone. The stratigraphic section was measured after the excavation, using a tape-measure. Other measurements were made by vernier caliper or ruler, as warranted.

Sampling for thermoluminescence (TL) dating (Aitken 1985; Wintle 1997) was carried out by Prescott and Hutton and several graduate students from the University of Adelaide Physics Department on 28 August, 1992 (Fig. 4).

Three horizontal auger holes were drilled into the bank (Fig. 5) to bracket vertically the position of the bones, which had been removed earlier. TL samples FR1S/0.9, FR1S/1.5 and FR1S/2.1 were collected for laboratory analysis, at depths below the top of the cutting of 0.9 m, 1.5 m, and 2.1 m, respectively. *In situ* gamma ray spectrometer measurements were made in the same holes from which the TL samples were collected, at about 0.5 m depth into the exposed face of the cutting.

---

[1] South Australian Museum, North Terrace, Adelaide S.A 5000.

[2] Department of Physics and Mathematical Physics, The University of Adelaide SA 5005

[3] Dr John Hutton died during the early stages of preparation of this paper

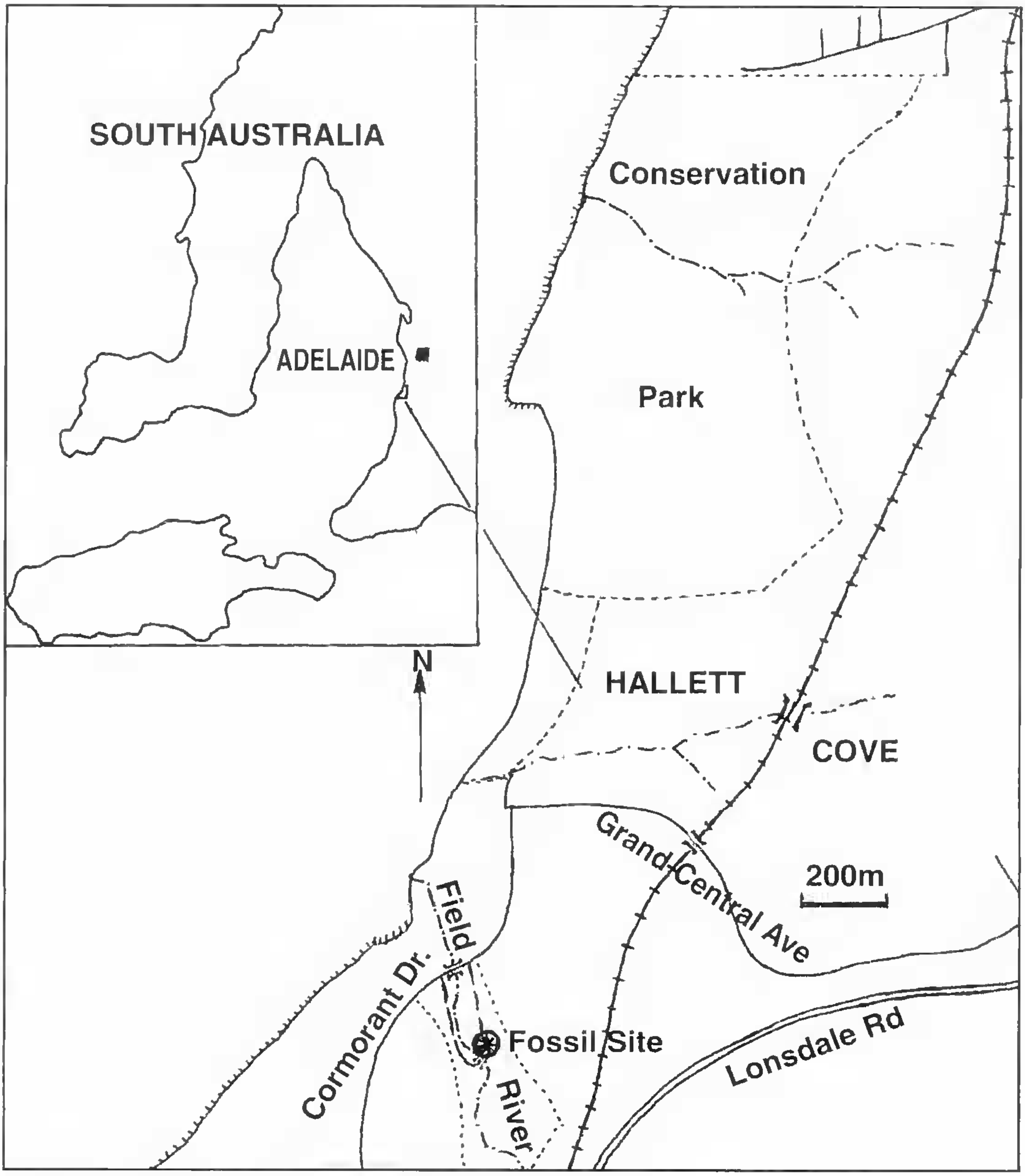

Fig. 1. Locality map; the fossil site is in a council reserve on the Field River.

Gamma ray spectrometry gives a direct measure of the radiation dose rate due to gamma radiation under prevailing field conditions and subsequent data analysis gives the concentrations of K, U and Th. These are then used for calculating the total dose rates from radiation in the environment, and for comparison with independent measurements in an assessment of the likelihood of radioactive disequilibrium in the deposits.

The age is calculated from the *age equation*:

$$\text{age (ka)} = \frac{\text{Equivalent dose (Gy)}}{\text{dose rate (Gy/ka)}}$$

where doses are measured in grays (Gy) and ages in kiloyears (ka).

Quartz grains in the 90–125 µm size range were extracted from the samples by standard procedures (Huntley *et al.* 1993).

The *selective bleach* method was used to find the

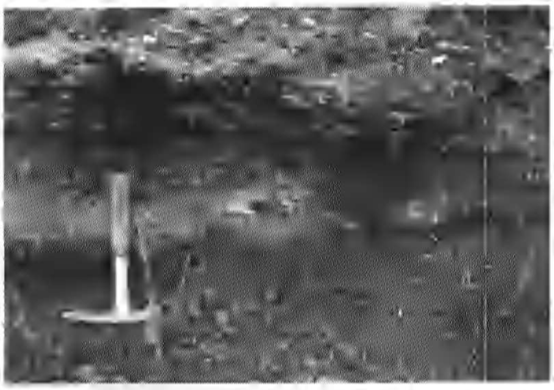

Fig. 2. The fossil bone as initially exposed in sandy lens between gravel layers. Hammer is 300 mm long.

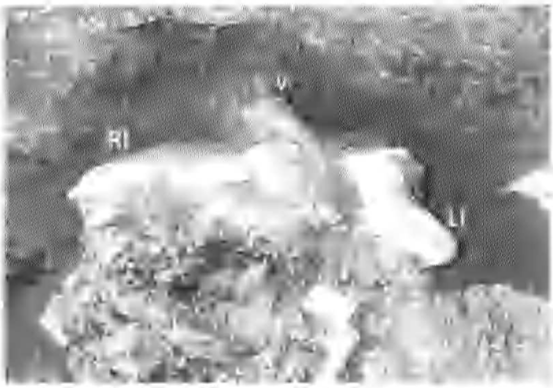

Fig. 3. The excavated *Diprotodon* pelvis, *in situ*. The skeletal fragment is upside down; anterior into the bank. The card by the hammer handle is 90 x 55 mm. LI, left ischium; RI, right ilium; V, vertebrae.

Fig. 4. *Diprotodon* fossil site, general view, eastwards, Field River at right. Preparations being made for thermoluminescence dating by Adelaide University Physics Department staff and students; the late Dr John Hutton second from right, Prof. John Prescott at right.

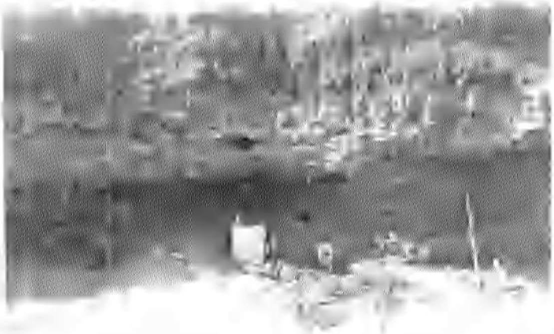

Fig. 5. Hallett Cove thermoluminescence sampling sites, showing general stratigraphy, central hole is at the fossil horizon. *In situ* gamma ray scintillation counting is taking place in the lowest hole.

equivalent doses (Prescott & Mojarrabi 1993). This method was developed to reduce the uncertainty in the level of solar bleaching, which resets the TL clock. The protocol uses optical filters to select the rapidly bleached component of the TL. The equivalent dose is determined by comparing the natural TL signal with one generated in the laboratory by a standard radioactive source. The specific method is known as 'The Australian Slide' (Prescott *et al.* 1993).

Results

The fossils

The main specimen was found to comprise parts of both left and right pelves still articulated with the sacral vertebrae, plus an adjoining lumbar vertebra and a fragment of the first caudal (SAM P33487), and is considered to represent the giant marsupial *Diprotodon* Owen 1839 (Fig. 3).

The pelves form a fairly flat plate at a slight angle to the vertebral axis. The acetabulum diameter is about 100 mm, the semi inter-acetabular width (right side) is about 200 mm, the sacral length about 150 mm and the ischio-iliac length is about 440 mm. The vertebrae are not well preserved except for their neural arches; a lumbar vertebra has a centrum with a transverse diameter of about 80 mm and length of 60 mm. These measurements are within the range of specimens of *Diprotodon* spp. from Lake Callabonna in the collections of the South Australian Museum and, after comparison with the pelvis of a skeleton displayed in the South Australian Museum, the Hallett Cove specimen is considered to be a subadult or female individual. Specific identity is not possible on the material preserved.

Preservation is not good. The bones are not petrified, being rather chalky, leached and unmineralised and held together largely by the supporting sandy loam. This circumstance proved to be both a help and a hindrance during the preparation of the specimen, as the bone was fairly easily cleaned but had to be consolidated and strengthened during the process because it would not support much weight. The specimen is consequently fragile with numerous fine cracks presumably associated with soil movement. The lower surface of the specimen in the sediment (the animal's dorsal side) is fairly complete with only some crushing of high points such as the dorsal processes of the neural arches. The opposite surface is less well-preserved with much missing bone and irregular ends, presumably where exposed, unburied parts had been eroded by the elements or incoming sediment. Although soft and susceptible to later damage, no cut marks, either from scavenger teeth or hunter's tools, were seen on any bone but no limb bones, which might have been a more attractive target, are present.

In the process of excavation, a few more bones were found in close association with the pelvis. One of these bones, a fragment of immature left mandible (SAM P35074), supported the identification of the pelvis as *Diprotodon*. This specimen, from which erupting cheek-teeth had fallen leaving only a barely worn incisor, is only 42 mm deep at the first molar alveolus, as compared to 100–110 mm or more in adult animals. Fragments of a little-worn M_1 of *Diprotodon* were also found. Another bone was of a large kangaroo, *Macropus*? sp. Several shells of small saxicolous land snails, *Succinea australis* Férussac, 1821 (Succinidae) and *Pericloeystis ardeni* Iredale, 1937 (Helicarionidae) (R. Hamilton-Bruce, pers. comm. 6 July 2001), apparently the first recorded fossil occurrence of these species in Australia), occur in the fine sediment surrounding the bones, together with fragile moulds of fine stems such as are seen in *Chara*-limestones in modern stream-pool deposits.

Geology

The fossiliferous sequence appears to be a marginal facies of the Pooraka Formation, recently redated by Bourman *et al.* (1997). Much of the *Diprotodon* skeleton had been lost, either by disarticulation or erosion before complete burial, or as a result of road-building excavations. The remaining bones lay upside-down in a shallow depression filled with poorly-sorted coarse sand, on a bed of somewhat current-imbricated pebbles of Precambrian sandstone and shale of apparently local origin (Fig. 3). The sandy horizon is lenticular and extends several metres on either side of the bones before pinching out. The pebbles, ranging up to some 5 cm in diameter, occur in beds 10 to 30 cm thick above and below the sand and are subangular to subrounded. Similar beds, alternating with sandier horizons, occur throughout the sequence exposed in the cutting. Bedrock of steeply-dipping, slightly metamorphosed Proterozoic slates and quartzites occurs within 10 m laterally, and evidently forms part of the original valley wall.

The stratigraphic sequence at the site of the bones is summarised below.

Soil—at least 0.5 m at top of cutting.

Flaggy, sheety, calcrete-cemented coarse gravel, pale brown—0.55 m.

Marly silty sand, pale pinkish buff—0.30 m. TL sample FR1S/0.9.

Fine (up to 10 mm) bedded gravel lens, becoming coarser to east and west, buff—0.10 m.

Marly silty sand, pale buff—0.20 m, pinching out laterally. Bones and saxicolous snails within this interval. TL sample FR1S/1.5.

Coarse gravelly sand, angular clasts up to 50 mm, roughly imbricated, light brown—0.20 m, thickening either side.

Brown silty clay—no base seen. Estimated depth to bridge level—1 to 2 m. TL sample FR1S/2.1 near top of this unit (see Fig.5). Height of bridge above standing water level about 3 m.

Age

Unfortunately, the quartz TL sometimes reaches dose saturation at a relatively low dose level and here, the two deepest samples, FR1S/1.5 and FR1S/2.1 were approaching this saturation. A consequence is the relatively large uncertainty in the age of FR1S/1.5. A pilot measurement on FR1S/2.1 showed that it was unlikely to yield a date for the same reason and so dating was not attempted. The pilot result is consistent with this sample being the oldest of the three.

Elemental analyses were obtained from field

TABLE 1. *Components of the age calculation and the ages for the two dated samples.*

sample	Lab. Code	equivalent Dose (Gy)	Dose-rate ($Gy\ ka^{-1}$) scint	Dose-rate ($Gy\ ka^{-1}$) XRS, NAA, alpha	averaged age (ka)
FR1S/0.9	AdTL94001	83±9	1.94±0.07	1.84±0.06	44±5
FR1S/1.5	AdTL94002	147±19	2.70±0.08	2.65±0.09	55±7
FR1S/2.1	—	—	2.75±0.11	2.94±0.15	—

gamma ray scintillometry for K, U and Th; by X-ray spectrometry (XRS) for K; and by thick source alpha particle counting (TSAC) for U and Th. The thorium concentration was checked by neutron activation analysis (NAA) for FR1S/0.9 and FR1S/1.5. Good agreement among the methods indicates that, within the uncertainties of measurement, there is no radioactive disequilibrium in the samples.

Table 1 shows the components of the age calculation and the ages for the two dated samples.

Discussion and Interpretation

Comments on Table 1

The equivalent dose and its error are output from a statistical fitting programme. The errors are relatively large because the inherent variability of quartz TL and the near dose-saturation of the TL make precise curve-fitting problematic. For FR1S/0.9, the fitting programme encountered no difficulties and there was a satisfactory dose plateau. Sample FR1S/1.5 was quite close to dose saturation and has a somewhat larger uncertainty.

There are two independent values for the dose rate: (1) field gamma ray scintillometry and (2) XRS for K, NAA for Th, thick source alpha counting for U. The agreement between them is gratifying. A contribution from cosmic rays is included (Prescott & Hutton 1994). Although no equivalent dose (and no age) was measured for FR1S/2.1, the dose-rate data are included for completeness.

The error in age is determined almost exclusively by the uncertainty in the equivalent dose. The equivalent dose and age of FR1S/0.9 are well described by the quoted figures. For FR1S/1.5 the dose curve is approaching saturation. Although the error quoted for the equivalent dose is objectively found by the fitting procedures, the error limits in the age are asymmetric. This asymmetry lies within the limits shown in the table which are one standard error. At 95% confidence, with allowance for this asymmetry, the age lies within the interval 42–70 ka.

Systematic errors include variability of water content, because the dose rate depends on this. In keeping with Adelaide laboratory practice, the age is quoted for the observed water content (18% of dry weight for the whole profile). How much it may have varied in the past is a matter of professional judgement. For all levels at this site, a 1% increase in water results in a 1% decrease in dose rate. Thus, if the average water content in the past had been 1% higher, then the dose rate and the measured equivalent dose would have been lower and the present-day age estimate would be 1% low. Cosmic ray variability provides another possible source of systematic error but, at this site, it is of no consequence.

Geological history

Some 100 000 years ago, when world sea-levels were much lower and the Gulf St Vincent was a broad plain drained by the ancient River Vincent that flowed to join the River Murray to the east of the future Kangaroo Island, the ancestral Field River had a steeper gradient, and had cut a gorge back into the face of the Mt Lofty Ranges. As the sea rose from this lower level, the river's gradient decreased (and rainfall may also have decreased) and the gorge began to silt up.

It appears that, possibly during a local flash-flood some 55 thousand years ago, a *Diprotodon* died and was swept downstream with other bones that had been picked up along the way, until the stream velocity dropped and/or the carcass reached an ephemeral pool where it settled. Sand from the final flush of flood water came to rest on and around the body, which was not completely buried. The pool silted up and exposed bone disintegrated under the effects of the elements (Behrensmeyer 1978) and possibly scavengers. Later, another flood brought a layer of gravel, in a process that was to be repeated for centuries as the valley gradually filled with sediment.

The present gorge/valley was probably incised in the older sediments by a rejuvenated stream at the height of the last glacial maximum, when the gradient was again increased, or in the early Holocene, when rainfall increased. It is possible that the very tumbled and beach-rolled isolated *Diprotodon* molar, found in 1971 by nine year-old Jonathon Dicker (Anon. 1971)[1] in beach gravels at the mouth of the Field River, was washed out at this time, but it is more likely that it was uncovered during the road-building operation earlier in the 20th Century and bull-dozed into the creek, to be carried by flood-waters to the sea.

The site of the *Diprotodon* bones has since been marked with a small cairn and plaque by the Hallett Cove Progress Association.

The age of this specimen, as presented here, is close to that of the putative arrival of the first Aborigines in Australia (Thorne *et al.* 1999; but see Bowler & Magee 2000; Gillespie & Roberts 2000). A human factor has been suggested in the Australian megafaunal extinction (Flannery 1994), either by direct hunting or by environmental modification, and certain sites, e.g. Cuddie Springs, northwestern New South Wales (Field & Dodson 1999), have been claimed to show evidence of interaction between humans and megafauna; this has been challenged for Cuddie Springs (Roberts *et al.* 2001). The Hallett

---

[1] ANON. 1971 Boy finds ancient tooth at beach. *The Advertiser* 21 May.

Cove specimen gives no indication of butchery, nor indeed of scavenging, with the remaining bones still articulated. It cannot therefore be used as evidence either way.

Conclusions

Fossil bones found in Quaternary sediments in the bank of the Field River, Hallett Cove, represent the partial skeleton of, probably, an immature *Diprotodon*, which was buried in an overbank deposit of the ancestral stream. Thermoluminescence dating of the sediments has given an age of between 42–70 thousand years before present at the 95% confidence level. This is close to the proposed date (Roberts *et al.* 2001) of 46 400 years BP for the megafaunal extinction event in Australia. However, there is no indication of a human factor involved in the death of this animal.

Acknowledgments

We thank the following for their help in the field and the laboratory: B. J. McHenry, J. A. McNamara, G. J. Prideaux, P. Stamatelopoulos and T. Westlake. The project was assisted by a grant to JP from the Australian Institute of Nuclear Science and Engineering.

References

Aitken, M. J. (1985) "Thermoluminescent Dating" (Academic Press, London).

Behrensmeyer, A. K. (1978) Taphonomic and ecologic information from bone weathering. *Paleobiology* **4**, 150–162.

Boerman, R. P., Martinaitis, P., Prescott, J. R. & Belperio, A. P. (1997) The age of the Pooraka Formation and its implications, with some preliminary results from luminescence dating. *Trans. R. Soc. S. Aust* **121**, 83–94.

Bowler, J. M. & Magee, J. W. (2000) Redating Australia's oldest human remains: a sceptic's view. *J. hum. Evol.* **38**, 719–726.

Chappell, J., Head, J. & Magee, J. (1996) Beyond the radiocarbon limit in Australian archaeology and Quaternary research. *Antiquity* **70**, 543–552.

Field, J. & Dodson, J. (1999) Late Pleistocene megafauna and archaeology from Cuddie Springs, Southeastern Australia. *Proc. Prehist. Soc.* **65**, 275–301.

Flannery, T. F. (1994) "The Future Eaters: an ecological history of the Australasian lands and people" (Reed, Sydney).

Gillespie, R. & Roberts, R. G. (2000) On the reliability of age estimates for human remains at Lake Mungo. *J. hum. Evol.* **38**,727–732.

Huntley, D. J., Hutton, J. T. & Prescott, J. R. (1993) The stranded beach-dune sequence of south-east South Australia: a test of thermoluminescence dating, 0–800 ka. *Quat. Sci. Revs* **12**, 1–20.

Prescott, J. R., Huntley, D. J. & Hutton, J. T. (1993) Estimation of equivalent dose in thermoluminescence dating—the 'Australian slide' method. *Ancient TL* **11**, 1–5.

__________ & Hutton, J. T. (1994) Cosmic ray contribution to dose rates for luminescence and ESR dating. *Radiation Measurements* **23**, 497–500.

__________ & Mojarrabi, B. (1993) Selective Bleach—An improved 'partial bleach' method of finding equivalent doses for thermoluminescence dating of quartz. *Ancient TL* **11**, 27–30.

Roberts, R. G., Flannery, T. F., Ayliffe, L. K., Yoshida, K., Olley, J. M., Prideaux, G. J., Laslett, G. M., Baynes, A., Smith, M. A., Jones, R. & Smith, B. L. (2001) New ages for the last Australian Megafauna: continent-wide extinction about 46,000 years ago. *Science* **292**, 1888–1892.

Thorne, A., Grun, R., Mortimer, G., Spooner, N. A., Simpson, J. J., McCulloch, M., Taylor, L. & Curnoe, D. (1999) Australia's oldest human remains: age of the Lake Mungo 3 skeleton. *J. hum. Evol.* **36**, 591–612.

Wintle, A. G. (1997) Luminescence dating: laboratory procedures and protocols. *Radiation Measurements* **27**, 769–817.